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Age and growth of hake *Merluccius merluccius* Linnaeus, 1758 from the Northeast Atlantic (ICES division IXa)

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ABSTRACT

The present study estimates age and growth parameters of the European hake *Merluccius merluccius* Linnaeus, 1758 from the Northeast Atlantic (ICES division IXa, Portuguese continental waters), based on otolith analysis. A total of 951 otoliths sections were examined, covering a length range of 10-80 cm, from fish taken during surveys carried out between October 1996 and July 1997. The annual ring interpretation followed the recently established standard ageing criteria, particularly for the first age groups. Quarterly age-length keys, for combined sexes, and the respective mean length at age were obtained. An indirect validation based on length-frequency analysis was performed using the Bhattacharya method. The estimated Von Bertalanffy growth parameters were L_∞ = 110.6 cm, k = 0.08 year^{-1} and t_0 = –0.97 year. These values are similar to those reported by other authors for the same species.

Key words: Hake, *Merluccius merluccius,* age, growth, otoliths, Portuguese waters, Northeast Atlantic.

RESUMEN

Edad y crecimiento de merluza* Merluccius merluccius *Linnaeus, 1758 del Atlántico nordeste (división IXa del CIEM)

El objetivo de este estudio fue estimar los parámetros de edad y crecimiento de la merluza europea Merluccius merluccius *Linnaeus, 1758 del nordeste atlántico (división IXa del CIEM, aguas continentales portuguesas), mediante el análisis de otolitos. Se observaron en total 951 cortes de otolitos, cubriendo un rango de longitud de peces de 10 a 80 cm, capturados en campañas realizadas entre octubre de 1996 y julio de 1997. La interpretación de los anillos anuales siguió los últimos criterios adoptados sobre atribución de edades, particularmente para los primeros grupos de edad. Se obtuvieron las claves trimestrales de edad-longitud considerando los sexos conjuntamente, así como la longitud media observada por edad. Se ha realizado una validación indirecta de los resultados basada en el análisis de las frecuencias de tallas utilizando el método de Bhattacharya. Los parámetros de crecimiento de la ecuación de Von Bertalanffy fueron L_∞ = 110,6 cm, k = 0,08 años^{-1} y t_0 = –0,97 años, valores similares a los estimados por otros autores para esta especie.*

Palabras clave: *Merluza,* Merluccius merluccius*, edad, crecimiento, otolitos, aguas portuguesas, Atlántico nordeste.*

INTRODUCTION

The European hake *Merluccius merluccius* Linnaeus, 1758 is one of the most important commercial species in Portuguese continental waters, mainly exploited by trawl and gillnets. For management purposes, two stocks of this species have been recognised in the Northeast Atlantic since 1978. Portuguese hake is considered to belong to the southern stock (ICES Divisions VIIIc and IXa).

A fundamental requirement for management of any heavily exploited resource, such as hake, requires an accurate knowledge of its annual age composition and growth. Although there is a large body of information on age and growth of *M. merluccius* in different parts of the Northeast Atlantic, there are still obstacles to an international, standard criteria for otolith interpretation. Indeed, there is a general consensus in the literature that the ring structure of European hake otoliths is difficult to interpret. Factors such as the definition of the otolith nucleus, formation of annual or false rings, and an extended spawning period, all contribute to the discrepancies between different otolith readings (Morales-Nin *et al.*, 1998).

Within the framework of two EC Study Contracts, involving the countries that traditionally exploit *M. merluccius* stocks, two workshops were conducted (Anon., 1997; Piñeiro *et al.*, 1999) to reach a consensus on an ageing criteria for hake otolith interpretation. Although some difficulties remain, guidelines were adopted for interpreting the otolith rings formed during the first three years of hake life, considering combined sexes (Anon., 1997).

Hake growth studies available for the Portuguese coast till 1998 were based only on length- frequency analysis (Cardador, 1988). Therefore, studies on age and growth of hake based on otoliths were undertaken in order to obtain reliable age-length keys, which could be used to improve *M. merluccius* stock assessment and management. Considering the fact that inaccurate age estimation can lead to to incorrect growth-rate estimates and consequent errors in estimating stock productions (Ricker, 1969), age validation studies are essential (Beamish and McFarlane, 1983).

MATERIALS AND METHODS

Sampling

M. merluccius samples for ageing were obtained from four research surveys carried out from October 1996 to July 1997, conducted during one month each quarter. For each 1 cm length-class, 6 specimens were sampled, considering combined sexes. Total fish length was recorded and the sagittae were collected.

Ageing methodology

We examined 951 pairs of otoliths, which were stored in individual vials with salted water until mounting with a black resin (Epoxy), and then sliced into thin sections on the nucleus level. Strips containing the otolith sections were stuck onto black polyester plates with Entalan (Piñeiro Álvarez, Padín Fernández and Loureiro Caride, 1996). Before observation, otolith sections were soaked in immersion oil to enhance translucent rings. A stereomicroscope (×20 magnification) with reflected light was used. Otolith interpretation was supported with ring measurements taken using a micrometer scale.

All areas of the otolith sections were observed in order to examine their annual rings. However, as growth does not occur equally on all axes, the ventral area –where growth zones are more readily distinguished– was chosen for ring interpretation.

Otolith interpretation

Otolith interpretation was performed according to the ageing criteria established at the hake workshop (Anon., 1997) as follows:

The possible existence of three false rings (larval, pelagic and demersal) deposited during the first year of hake life, before the first translucent annual ring is formed (figure 1a).

The frequent existence of a false (strongly marked translucent) ring between the first and second annual rings, or coincident with one of them, considered to be related to some event in the fish's life-cycle (figure 1b). This false ring was considered as a reference check ring (CH).

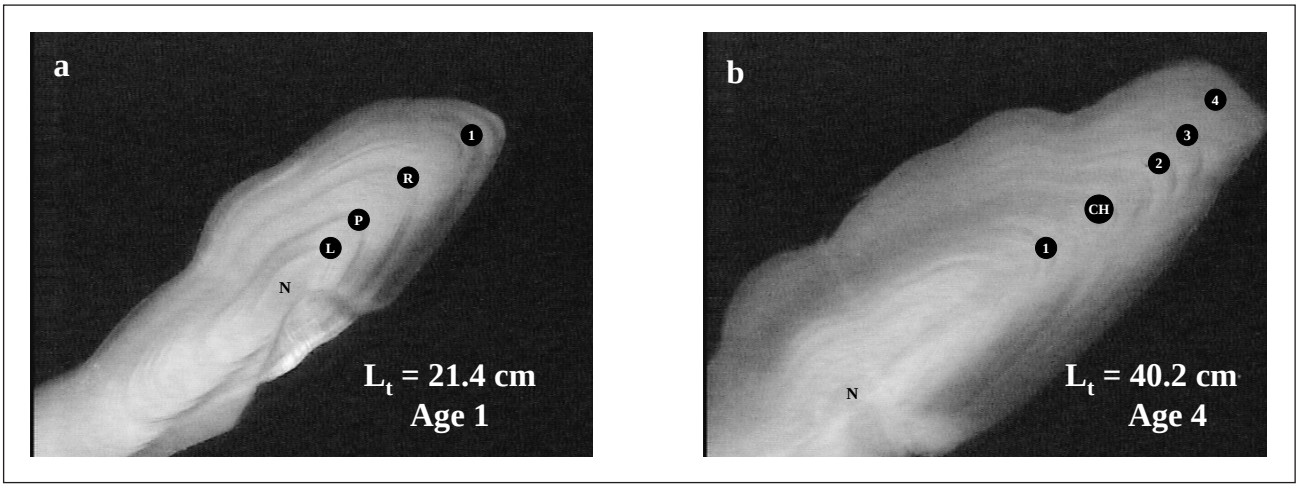

Figure 1. Hake otoliths sections (×20 magnification) collected during the second semester. (N): nucleus; (L): larval; (P): pelagic; (D): demersal; (CH): check; 1, 2, 3 and 4 annual rings

The first of January was considered the birthdate for edge interpretation.

Growth parameters

We estimated the *M. merluccius* growth parameters, assuming that it followed the Von Bertalanffy growth curve (Von Bertalanffy, 1938).

In order to estimate growth parameters, two exercises were carried out:

1) Considering all the fish aged for the four quarters (October 1996 to July 1997), from age 0 to 10.

2) Considering only the age-length key, combining the three quarters of 1997.

In the first exercise, we adjusted the observed individual age, as follows:

4th Quarter 1996	Observed age (years)	+ 0.75
1st Quarter 1997	Observed age (")	
2nd Quarter 1997	Observed age (")	+ 0.25
3rd Quarter 1997	Observed age (")	+ 0.50

This adjustment was intended to minimise the possible bias introduced by differences in the sampling time on the growth parameter estimation.

Auximetric analysis

The concept of Growth Performance Index introduced by Pauly and Munro (1984) makes it possible to directly compare the growth performance of different populations of the same species, based on Von Bertalanffy growth parameters. The Performance Index (θ), calculated as $\theta = log_{10} K + 2\ log_{10} L_\infty$ (Pauly and Munro, 1984) was estimated using the growth parameters L_∞ and K obtained in this study (exercise 1). The values considered for comparison included only parameters estimated for combined sexes in the Atlantic Northeast area.

Length composition analysis

Considering that information on the length composition of the *M. merluccius* population was available from catch surveys, an exercise was performed applying the Bhattacharya method (Bhattacharya, 1967). Its purpose was to identify the existence of modal length groups that could validate the age information obtained from otoliths. For this analysis, the FISAT software package (Gaynilo, Sparre and Pauly, 1994) was used. Length frequency analysis tends to lump the final age classes together if they are in close proximity or contain a small percentage of fish (Schnute and Fournier, 1980). Taking this into account, only the more evident modal groups were considered for validation purposes.

The Bhattacharya method was also applied to the hake length composition data available from a research survey conducted during the 4th quarter (October) of 1997 to check if data regarding the 4th quarter of 1996 could be considered to complete a calendar year growth for 1997.

RESULTS

Age-length keys for the 4th quarter of 1996 and the first three quarters of 1997 were obtained for combined sexes. The respective mean lengths at age are presented in table I. The age data regarding the three quarters of 1997 were combined in a global age-length key, and the respective mean lengths at age are also presented in table I.

The estimated growth parameters obtained in exercises 1 and 2 are presented in table II and their growth curves are shown in figures 2a and 2b.

In exercise 2, a decrease in the L_∞ value was observed, probably related to the absence of growth expected for the 4th quarter.

The growth parameters obtained in the two exercises were compared to those obtained in previous studies developed for *M. merluccius*, considering only combined sexes (table III). In the same table, the Growth Performance Index (θ) for each study is also presented for direct comparison. The θ values obtained in this study are similar to those estimated for other studies (table III).

The estimated mean length at age, based on the Von Bertalanffy parameters obtained in exercise 1,

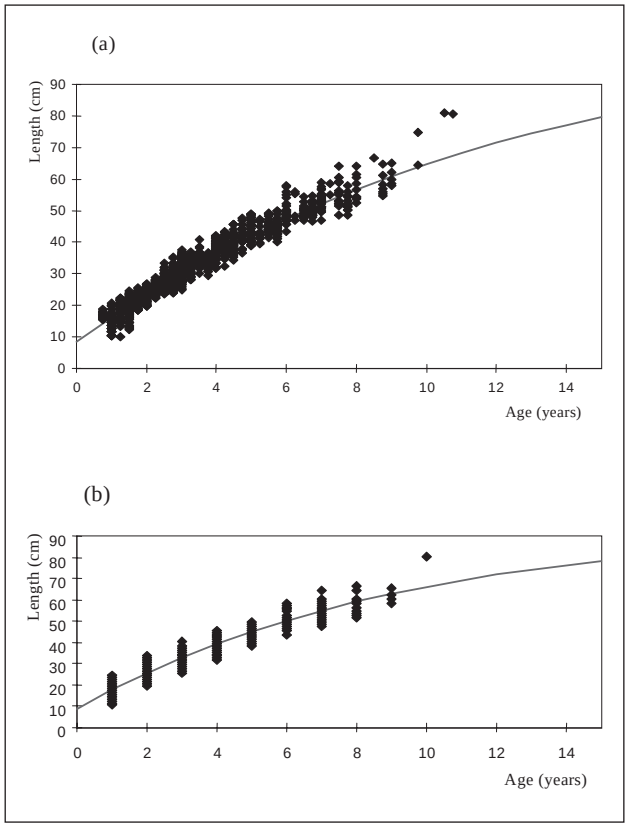

Figure 2. (a): Hake growth curve estimated in exercise1; (b): hake growth curve estimated in exercise 2

Table I. Mean length (L_t) at age and observed number (n) of hake otoliths

Age	4th quarter - 96		1st quarter - 97		2nd quarter - 97		3rd quarter - 97		Combined - 97	
	Mean L_t	n	Mean L_t	n	Mean L_t	n	Mean L_t	n	Mean L_t	n
0	16.7	20	–	–	–	–	–	–	–	–
1	21.5	37	14.6	53	18.0	52	18.9	58	17.1	163
2	28.6	45	23.4	60	25.5	35	27.9	48	25.6	143
3	34.0	27	31.2	74	32.5	32	34.5	27	32.3	133
4	42.1	23	37.6	38	36.2	34	39.9	42	39.0	114
5	44.9	27	43.8	30	43.1	14	45.2	22	44.2	66
6	50.4	21	49.9	28	51.7	4	49.8	14	50.3	46
7	52.7	15	53.0	27	56.9	2	55.4	14	54.1	43
8	58.2	8	57.3	10	–	–	66.7	1	57.5	11
9	69.6	2	60.7	5	–	–	–	–	60.7	5
10	80.5	1	–	–	–	–	80.9	1	80.9	1
Total		226		325		173		227		725

Table II. Estimated hake growth parameters and respective r^2 (exercise 1 and 2)

						Age (years)		Length (cm)	
	N	L_∞	k	t_0	r^2	Min.	Max.	Min.	Max.
Exercise 1	899	110.6	0.08	–0.97	94.2	0	10	10.1	80.9
Exercise 2	725	94.9	0.11	–0.87	93.4	1	10	10.1	80.9

Table III. Hake growth parameters for combined sexes obtained in different studies in Northeast Atlantic and the respective Growth Performance Indices. (*): Length Frequency Analysis

	L_∞ (cm)	K (year^{-1})	t_0 (year)	θ
This study (Exercise 1)	110.6	0.08	–0.97	2.99
This study (Exercise 2)	94.9	0.11	0.87	3.00
Cardador (1988) (*)	102.3	0.06	–	2.80
Goñi (1983)	110.0	0.064	–0.76	2.89
Hickling (1933)	128.6	0.087	–	2.78
Iglesias and Dery (1981)	99.9	0.06	–2.74	2.90
Oliver, Morillas and Gaza (1992) (*)	94.2	0.09	–0.59	3.03
Pauly (1978)	105.0	0.184	–	3.04
Pauly (1978)	83.9	0.296	–	3.31
Piñeiro *et al.* (1997)	120.0	0.074	–1.23	3.32
Robles *et al.* (1975)	125.4	0.070	–0.40	3.16

are presented in table IV, as well as the annual length increment (ΔL).

The application of the Bhattacharya method to the *M. merluccius* length compositions enabled us to identify four modal length groups, related to different ages, which gradually increase from quarter to quarter. A comparison between these four modal length groups, and the mean length at age obtained for ages 1 to 4 based on the otolith age reading, showed a close similarity (table V).

The presence of two modal length groups, at 15.1 and 22.0 cm, identified for the 3rd quarter of 1997, considered to represent age 1 (table V), may confirm the existence of two *M. merluccius* spawning peaks, reported by several other authors (Goñi, 1983; Aldebert, 1994; Recasens, in Morales-Nin *et al.*, 1998). Moreover, the existence of two modal groups with mean lengths of 11.8 and 17.2 cm for the 4th quarter of 1996, assumed to represent age zero, can be considered a consequence of that spawning behaviour.

The comparison of length composition results obtained for surveys in the 4th quarter of 1996 and 4th quarter of 1997 showed a close similarity between the modal groups present in both surveys (table V). This led us to assume that the length composition data from the four surveys used in the present study could be taken as representative of 1997 calendar-year growth.

Table IV. Hake estimated length at age (exercise 1) and annual length increment (ΔL)

Age (year)	Estimated length (cm)	ΔL (cm)
0	8.3	7.8
1	16.1	7.3
2	23.4	6.7
3	30.1	6.2
4	36.3	5.7
5	42.0	5.3
6	47.3	4.8
7	52.1	4.5
8	56.6	4.2
9	60.8	3.8
10	64.6	–

Table V. Hake mean length at age obtained with Bhattacharya Method (A) and otolith observation (B), considering the sample period

Age	1st quarter -97		2nd quarter - 97		3rd quarter - 97		4th quarter - 96		4th quarter - 97
	A	B	A	B	A	B	A	B	A
0							11.8	16.7	10.1
							17.2		16.7
1	14.4	14.6	19.4	18.0	15.1	18.9	21.8	21.5	21.7
					22.0				
2	22.8	23.4	24.7	25.5	28.8	27.9	29.0	28.6	28.0
3	30.5	31.2	32.2	32.5	34.2	34.5	35.3	34.0	35.4
4	34.7	37.6	35.3	36.2	40.2	39.9	42.9	42.1	
5		43.8		43.1	43.2	45.2		44.9	
6		49.9		51.7	48.0	49.8		50.4	
7		53.0		56.9	53.3	55.4		52.7	
8		57.3				66.7		58.2	
9		60.7						69.6	
10						80.9		80.5	

DISCUSSION AND COMMENTS

M. merluccius ageing studies based on otolith readings can provide highly valuable information, due to the recognised importance for stock assessment of reliable data regarding the catch's age structure, and also, in this specific case, to the fact that the information available for the Portuguese catches relied on length composition analysis. The results presented in this study are a contribution to more accurate estimations of the mean length at age and growth parameters of *M. merluccius* in the Portuguese coast, based on otolith interpretation.

Growth parameters were estimated considering combined sexes, even though it is known that females attain larger sizes (and ages) than males (Descamps and Labastie, 1978; Iglesias and Dery, 1981). The L_∞ value (110.6 cm) obtained in this study is similar to those reported by other authors for the same species (Robles *et al.*, 1975; Iglesias and Dery, 1981; Goñi, 1983; Cardador, 1988; Oliver, Morillas and Gaza, 1992; Piñeiro *et al.*, 1997). However, considering that lengths of more than 50 cm were poorly represented in our surveys, mainly for the 2nd and 3rd quarters of 1997 (probably due to the unavailability of those lengths to trawl gear), the estimated value of L_∞ (110.6 cm) can be considered an underestimate. According to Pauly (1983), reasonable values of L_∞ can be obtained empirically, using the relation $L_{max}/0.95$, where L_{max} is the maximum length observed or reported. In the Portuguese national sampling programme, two *M. merluccius* specimens of 120 and 140 cm total length have been registered.

Otolith ring measurements were undertaken based on the assumption that if growth zones are annual they must appear at a similar distance from the otolith nucleus, at least for the fish born in the same spawning season. A good agreement was obtained for the location of the demersal (D), check (CH), and for the annual rings from ages 1 to 4 identified in the otolith ventral section area.

The comparison between the Bhattacharya results and the mean length at age from direct otolith age readings shows a close similarity for the values estimated for ages 1 to 4. Considering that the results based on length-frequency analysis are more reliable for the first ages, corresponding to periods of fast growth rates (Morales-Nin and Mosegaard, 1997), the observed similarity can be considered an indirect validation for those ages of *M. merluccius* on the Portuguese coast.

The mean length at ages 1 and 2 obtained in this study with the Bhattacharya method are close to, although slightly higher than, those obtained in a study using the same method (18 and 23.2 cm, respectively) with data from from surveys conducted between 1981 and 1987 (Cardador, 1988) on the Portuguese coast. Such differences can be related either to the subjectivity of the interpretation method (Schnute and Fournier, 1980) or a real change in *M. merluccius* growth, related to the decrease in abundance reported for the Atlantic hake stock during the 1990s (Anon., 2000).

In general terms, the *M. merluccius* growth results obtained in this study agree with those reported by several other authors for this species, particularly during the first years of life. There is a consensus in the literature that hake otolith interpretation is very difficult, and all authors report the presence of different false rings laid down in the otolith, mainly during the first years of life (Iglesias and Dery, 1981; Goñi, 1983; Goñi and Piñeiro, 1988; Piñeiro and Hunt, 1989; Álvarez and Pereiro, 1993). *M. merluccius* otolith analysis for Portuguese waters presents the same difficulties. Decisions regarding interpretation were supported by ring measurements and the recommended guidelines established during the hake workshop (Anon., 1997). In addition, since hake is a serial spawner (Sarano, 1986), subjective judgement was applied in assessing the first and second annual zone.

Several authors have found annual periodicity in otolith ring deposition for the genus *Merluccius,* e.g. Piñeiro and Hunt (1989) and Álvarez and Pereiro (1993) for *M. merluccius*, Dery (1988) and Hunt (1980) for *M. bilinearis* (Mitchill, 1814), Fernández (1987) for *M. gayi peruanus* (Ginsburg, 1954), Botha (1971) for *M. capensis* (Castelnau, 1861) and *M. paradoxus* (Franca, 1960), and Dark (1975 in Beamish, 1979) and Beamish (1979) for *M. productus* (Ayres, 1855). The present study's otolith ring measurements showed a good agreement for the location of annual rings identified in the ventral section area. Although these rings could not be identified in other areas, either because they were not visible (sulcal area) or were indistinguishable (dorsal area), they were considered as annual, which is supported by the results of the indirect validation. However, in a recent study on growth of *M. merluccius* in the Mediterranean (Morales-Nin *et al.*, 1998), based on ring measurements taken in the sulcal area of burnt sectioned

otoliths, the authors concluded that rings cannot be considered *annuli*. This finding may be specific to the Mediterranean hake.

Considering that data used in the present study were based on bottom-trawl survey catches, and larger specimens are caught mainly with gillnets (Anon., 2000), a future study should be carried out based on samples with a larger length range in order to obtain more complete hake growth knowledge. In addition, future morphometric studies on otoliths are recommended, which could result in a promising tool for indirect validation of age readings (Mosegaard and Morales-Nin, 2000), or even for a rapid prediction of fish age (Mug-Villanueva, Gallucci and Lai, 1994).

Although some improvements were achieved in interpreting Portuguese *M. merluccius* otoliths, major difficulties still remain:

The edge interpretation, due to the frequent presence of a translucent edge along the year, which may be related to the fact that this species is a serial spawner.

The rings are often indistinguishable on the internal and external surface of the otolith section, which can make it almost impossible to follow either the annual or the false rings all around the otolith area.

The difficulty in interpreting otoliths of older fish because growth occurs mainly on the ventral and dorsal edge, where translucent rings became irregular and too close to be identified (ventral area), or even indistinguishable (dorsal area).

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